# A ROBOT FOR WRIST REHABILITATION

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***Abstract* -In 1991, a novel robot named MIT-MANUS was introduced as a test bed to study the potential of using robots to assist in and quantify the neuro-rehabilitation of motor function. It proved an excellent fit for the rehabilitation of shoulder and elbow of stroke patients with results in clinical trials showing a reduction of impairment in these joints. The greater reduction in impairment was limited to the group of muscles exercised. This suggests a need for additional robots to rehabilitate other degrees of freedom. This paper outlines the mechanical design of a robot for wrist rehabilitation.**
***Keywords* - neurological, rehabilitation, stroke, robot, wrist.**

## I. Introduction

Rather than using robotics as an assistive technology, our research focuses on the development of robotics as a tool to enhance the productivity of clinicians in their efforts to facilitate a disabled individual's recovery. To that end, we deployed and commenced extensive clinical trials of our first robot, MIT-MANUS (see figure 1), at the Burke Rehabilitation Hospital, White Plains, NY in 1994 [5]. MIT-MANUS has been in daily operation for over 6 years, delivering therapy to over 100 stroke patients. Copies have been recently deployed at the Spaulding (Boston), Helen Hayes (NY), Baltimore & Cleveland VA Hospitals.

Our results suggest that goal oriented exercise of a hemiparetic limb appears to harness and promote the neuromotor recovery following a stroke [1, 5, 6, 10, 11].

Seventy-six stroke patients exhibiting a unilateral lesion were enrolled in the initial clinical trials. Patients were randomly assigned to an experimental and a control group. The experimental group received an hour per day of robot-aided therapy exercising the shoulder and elbow. The control group received an hour per week of "sham" robot-aided therapy with the same video games.

Fig.1. A recovering stroke patient receiving upper extremity robotic therapy with MIT-MANUS.

The results of the initial studies, as measured by standard clinical instruments, showed statistically significant difference between the experimental and control group for shoulder and elbow (the focus of the exercise routines), but no differences for wrist and fingers (which were not exercised). This result suggests a local effect with limited generalization of the benefits to the unexercised limb or muscle groups. If this is the case, we must extend our robot-aids to exercise different groups of muscles and limb segments. We are presently developing robots to work with different muscles and limb segments, e.g., spatial motion, wrist, fingers, legs [3, 4, 7]. In this paper, we describe the design of a device for wrist rehabilitation.

## II. Specification for a New Wrist Device

It is of paramount importance that the wrist device be easy for the therapist and the patient to use. To prevent daily use from becoming a chore for the patient and the therapist only a minimum amount of time and effort must be required to attach and remove the patient from the wrist device. The setup target time was estimated at 2 minutes maximum.

Another key aspect is low endpoint impedance. That is, when a patient attempts to backdrive the robot, the effective friction, inertia and stiffness should ideally be low enough such that it feels as if no robot is connected to the user. In this case, the robot hardware is termed "backdrivable". The maximum reflected inertia for backdriveability for each wrist degree of freedom was estimated to be 30 to $45.10^{-4}$ kg-m$^2$. The maximum reflected friction for backdriveability was estimated to be 0.2 N-m. The wrist device should also have ranges of motion of a normal wrist in everyday tasks, i.e., flexion/extension 70°/65°, abduction/adduction 15°/30°, pronation/supination 90°/90°. The torque output from the device must be capable of lifting the patient's hand against gravity, accelerating the inertia, and overcoming any tone. The estimated value for flexion/extension and abduction/adduction was 1.2 N-m and for pronation/supination 1.69 N-m [8, 12].

### A. Kinematic Selection

A curved slider was found to suffice for the robot's pronation/supination axis. A curved rail sits between four guide wheels, which allow it to rotate (see Figure 2). Several different options were considered for the remaining kinematics. These options must allow the patient to move in flexion/extension and abduction/adduction and also must

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allow the robot to apply torques to the patient's hand. After reviewing each of these kinematic options, a cardan joint was found to be the most appropriate (see Figure 3). A mockup is shown in figure 4.

*B. Actuator Placement and Transmission Selection*

Three major sub-categories emerged from the various actuator/transmission packages considered. The first option placed all actuators on the ground frame (see link 1 in figure 3). The second option placed an actuator on the ground and two actuators on link 2 (differential configuration). The last option placed an actuator on the ground frame, an actuator on link 2, and an actuator on link 3 (serial configuration)[9].

In comparing these options, the differential configuration clearly held the advantage. For the same actuators, the range of output torque was up to twice that of the serial configration. Another advantage over the serial configuration is that the actuators can more effectively counterbalance each other. This is because both actuators are placed on a single link (link 2). By symmetrically locating the actuators about the robot's pronation/supination axis, the torque due to the weight of the motors is canceled.

*C. Actuator Selection*

We limited our search to ultimag rotary actuators, servo-disc, DC-brushed and brushless motors. Of these, we selected the brushless motors, which deliver high torque and runs smoothly at low speeds, a requirement in this application [2]. The brushless motors also allow for better heat dissipation because the windings are on the stator.

In order to select from the many available brushless motors, the reflected output impedances for each axis of rotation were compared. The following brushless motors were deemed acceptable (< 0.5 kg): Parker series SM160A and SM161A, Pittman series 34x1,2 and 44x1,2,3, and the Kollmorgen series 512, 513, 711-714 actuators.

Figure 5 shows a sample of how the actuators were compared. In this case, we are comparing the added inertia in abduction/adduction and flexion/extension due to the motor. The abscissa shows the reduction ratio required for each motor to achieve the specified maximum output torque of 1.2 N-m. The ordinate shows the added inertia in both flexion/extension and abduction/adduction. This number was found by taking $2.I_m.R^2$, where $I_m$ is the inertia of the given motor armature, R is the reduction ratio and the factor of 2 is due to the fact that both motors on link 2 will be backdriven. In a similar fashion, we estimated the added friction in abduction/adduction and flexion/extension. A similar approach yielded estimates for pronation/supination.

We opted for the Kollmorgen's RBE 711 motors for the abduction/adduction and flexion/extension actuators and the RBE 712 motors for pronation/supination.

Because the flexion/extension and abduction/adduction

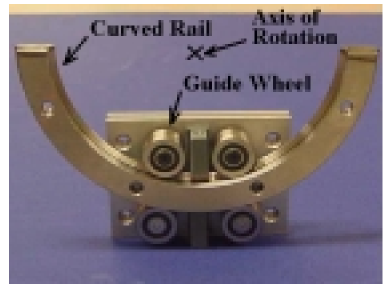


Fig.2. Curved Slider

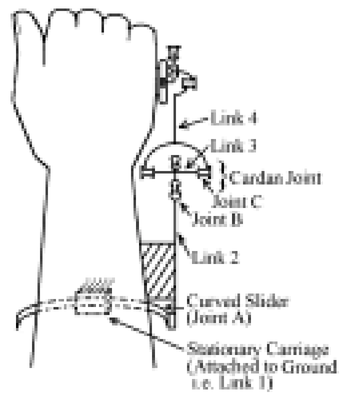


Fig.3. Cardan Joint Kinematics

Fig.4. Mockup in Flexion/Extension, Abduction/ Adduction, and Pronation/Supination

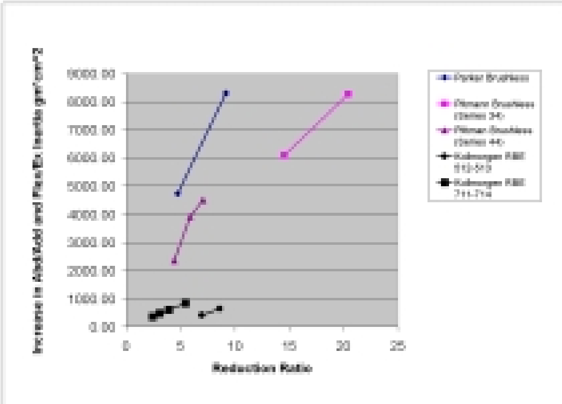


Fig. 5. Added Inertial Impedance in Flexion/Extension and Abduction/Adduction

motors will be in close proximity to the patient, a finite element analysis was performed to ensure that motor temperature would not rise to uncomfortable levels.

### *D. SENSOR SELECTION*

The determining factor in selecting the type of position feedback device was its size, servo-amplifier compatibility, and insensitivity to noise. The smallest system found was an incremental encoder from Gurley Precision, the R119. It is a high-resolution mini-encoder with 10,240 cycles per rev. Its size was well suited for the wrist device allowing for its placement inside of the transmission housing.

## III. HARDWARE OVERVIEW

To illustrate the proposed device, we will use Pro/Engineer™ solid models. Figure 6 shows the solid model and the complete device. Figure 7 illustrates how the patient's hand, wrist and upper forearm will be held on the device via a series of velcro straps: two straps over the back of the palm, a single strap over the proximal or middle phalanges, two straps to the wrist connection piece, and a strap over the forearm. Also shown is a protrusion, which prevents the hand from slipping around the handle. Figure 8 shows the transmission from the abduction/adduction and flexion/ extension actuators to the arm. To increase visibility, a section of the transmission housing has been removed in the close up view. The gears are also darkened to distinguish them from other components. Two spur gear trains are used to transmit torque from the actuators to the differential. The three bevel gears of the differential, the spider gear and the two end bevel gears, are represented by their pitch cones.

The two spur gear trains consist of four gears. These gears include the motor pinion gear (gear A), two intermediate gears which are rigidly attached and rotate together (gears B and C), and the endgear of the differential (gear D). The intermediate gears were added to keep the differential endgears and the rest of the transmission small. The total reduction in one train from the actuator pinion to the differential endgear is 8:1.

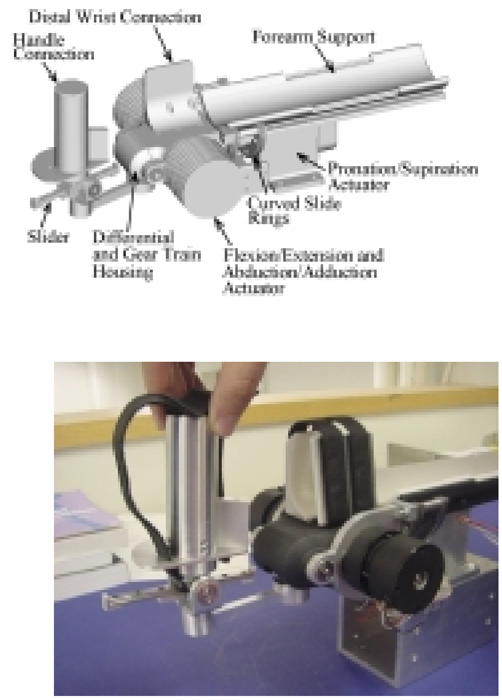


Fig. 6. Complete Wrist Device

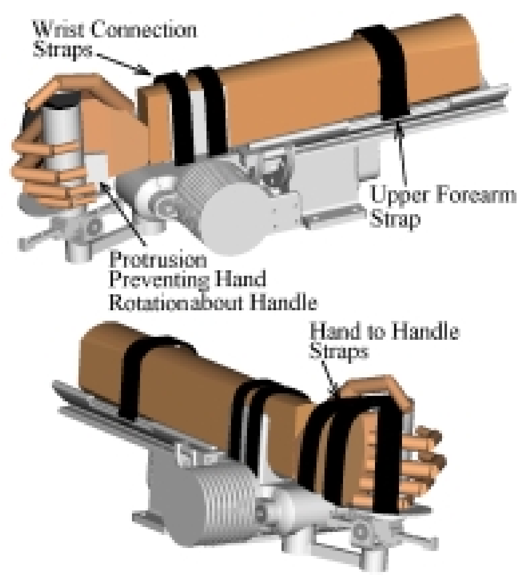


Fig. 7. Connection to the Patient

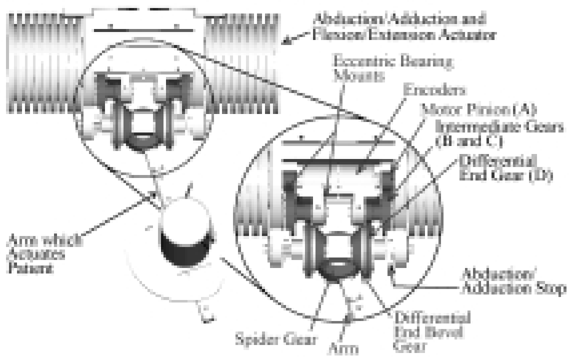


Fig 8. Transmission System for Abduction/Adduction & Flexion/Extension.

The two stops shown in figure 8 prevent over rotation of the patient in abduction and adduction. These stops also prevent the robot arm and handle components from contacting other components. They limit the range of motion to 30° in adduction and 20° in abduction. Although not shown, similar stops restrict rotation in flexion and extension. These stops limit rotation in flexion/extension to 60° in each direction.The final design is below specification by 10° in flexion and 5° in extension.

The axis for pronation and supination makes use of two geared 180°-slide rings. Each slide ring has opposing "V" shaped edges, which roll between four guide wheels with "V" shaped grooves. The lower two guide wheels are eccentric allowing adjustment in the preload of the wheels against the slide rings. The upper guide wheels are concentric and cannot be adjusted. Two stops limit the rotation of the wrist to 76° in pronation and 76° in supination, which is slightly below our target requirements of 90°.

## IV. Conclusion

Clinical results to date suggest that robot-aided neuro-rehabilitation can have a positive influence on neuro-recovery following a stroke. Our pioneering clinical results are consistent with a prominent theme of current neuroscience research into the sequelae of brain injury, which posits that activity-dependent plasticity underlies neuro-recovery. Furthermore, our results with more than 100 stroke patients open up a number of opportunities. We envision the rehabilitation clinic of the future as gyms of "rehabilitators" working with different limb segments, muscle groups, and functional tasks. At this gym, the therapist tailors an exercise routine to the particular patient's needs to optimize recovery, increasing the clinic's productivity by overseeing several patients at the same time. The productivity of the overall rehabilitation system may further be improved by the objective and precise measurements afforded by robotics, with the potential to automate the assessment and documentation of recovery. We also envision further improvements by extending treatment with robot-aids at patients' homes.

From the realm of science fiction to the substance of humbling reality, the novel module for wrist rehabilitation is another marker along the trail. It follows the same design guidelines of MIT-MANUS, which includes back-drivability. Our experience has shown that it is an important feature of any successful interactive robot-aid. On final note, while very little technology presently exists to support the recovery phase of rehabilitation, we believe the landscape will change quickly in the near future.

## V. Acknowledgment


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